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The upcoming new editions of IEC 60825-1 and ANSI Z136.1 – examples on impact for classification and exposure limits

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THE UPCOMING NEW EDITIONS OF IEC 60825-1 AND ANSI Z136.1 – EXAMPLES ON IMPACT FOR CLASSIFICATION AND EXPOSURE LIMITS

Paper #C102

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Abstract

The standards IEC 60825-1 for laser product classification and ANSI Z136.1 on user requirements are in the process of being revised, particularly regarding the retinal thermal MPEs and AEL for Class 1, 2 and 3R. For pulsed exposure, the basic multiple pulse rules will change significantly, as well as, on top of that, for extended sources, a time dependence α_{max} is introduced. The MPE/AEL is in rare cases smaller than the current value, but for most practical cases the new limits result in a significant increase of the permitted emission level for the "safe" classes or of the MPE for the eye (and therefore a decrease of the NOHD for Class 3B and Class 4). Examples will be presented that will demonstrate the effect of the changes.

Introduction

The international laser safety standard IEC 60825-1 [1] is currently revised [2] to be published as Edition 3 at the end of 2013. The changes of the retinal thermal maximum exposure limits (MPEs) for the eye are adopted from the ICNIRP guidelines (the IEC committee does not operate a bio-effects expert panel as the ANSI Z136 committee does). The ICNIRP guidelines [3] were amended in in parallel with ANSI Z136.1 [4] as they are both based on the same set of injury threshold data and there is also a significant overlap of expert members between the ANSI bioeffects subcommittee and ICNIRP Standing Committee IV on Optics.

Since the exposure limits (MPEs) for the eye are the direct basis for the AEL (accessible emission limits) for the laser product safety classes Class 1, 1M, 2, 2M and 3R [5], any changes in the MPE will also result in equivalent changes of the AEL values and thus in the permitted output powers for these classes. It is stressed here that with the exception of the wavelength range of 1250 - 1400 nm, **all the changes of the retinal thermal limits are relevant only for pulsed emission/exposure**. This means that the limit for cw lasers (such as 1 mW for Class 2, or 5 mW for Class 3R in the visible wavelength range) will not change (except for the wavelength range of 1250 nm to 1400 nm). Since Class 3B AELs (the border between Class 3B and Class 4) are not directly derived from MPEs, they will not be affected, but the NOHD of pulsed Class 3B and Class 4 systems will in most cases be affected. Regarding Class 3B it is noted that due to the change of the AEL of Class 3R (which is with exception of rare cases raised) some products that are now in the lower range of Class 3B will be become Class 3R or potentially even Class 2 (when in visible) or Class 1. Only in very rare cases will the permitted output level become more restrictive: for pulse durations less than 18 µs (50 µs for wavelengths above 1050 nm) for systems which emit at a very low repetition rate of less than 39 pulses within 10 s.

It is pointed out that IEC 60825-1 is also accepted by the CDRH for products sold in US as specified in Laser Notice 50 and therefore also has high significance also for the US market (ANSI Z136.1 is a standard regarding user safety measures and the classification scheme provided in the ANSI standard applies only on the laser user level).

Regarding the exposure limits that are defined in the European Directive on artificial optical radiation (AORD) [6] and the respective national transpositions which are by-laws to the work place safety legislation, it is pointed out that they were directly adopted from the ICNIRP guidelines, but it is not clear if and when the exposure limits for the workplace on the European level (the AORD) will be updated. As long as the exposure limits of the AORD are not amended, but the 3rd edition of EN 60825-1 (the European version, but usually identical with IEC 60825-1) is published and harmonized under the low-voltage directive, there will be cases where the conclusion, that Class 1 products do not emit levels of optical radiation that can exceed the exposure limits of the AORD is no longer generally valid. Therefore, the value of the classification of products as a simple way to avoid a more detailed hazard evaluation at the workplace will be diminished and it is hoped that also the AORD will be amended to reflect the updated ICNIRP guidelines.

This paper will concentrate on the changes of IEC 60825-1 MPEs and AELs, and, as noted, almost all changes are equivalent in ANSI Z136.1. There is a

deviation in the treatment of multiple pulses in the nanosecond range. These differences will be noted.

Amendments other than of the MPE or AEL will be listed but not discussed in detail, as they are also the topic of other papers in these proceedings.

Status of documents, timing

At the time of the ILSC 2013, the stage of the IEC document is at the Committee Draft for Voting (CDV) level. Voting and comment period ends at the end of March 2013. It depends on the voting results what the next stage is: if there are no “NO” votes from the national committees, the document can, after due consideration of the comments by the national committees, proceed directly to be published as international standard. If there are one or more “NO” votes, a Final Draft International Standard (FDIS) is necessary which will delay the publication of the standard by about three months. The exact date of publication also depends on how fast the final editing is done at the IEC central office, but the project is within the time schedule set out in the beginning of the project, where the IEC lists October 2013 as publication date, which included the possibility of an FDIS.

The ANSI Z136.1 document is at the time of writing of this article (Jan 2013) in the final stages of the approval to be released as CDV and publication can be assumed to be in 2014.

Changes other than MPEs and AEL

There are some significant changes in IEC 60825-1 not directly related to MPEs and AEL values, and the main ones are listed here but not discussed in great detail.

Removal of Condition 2

Condition 2 (the “eye loupe” condition) is removed from the measurement condition requirements. This leaves Condition 1 (telescope condition) and Condition 3 (naked-eye condition), which are not renamed or renumbered. A special measurement and testing condition that considers usage of high-magnification lenses for highly diverging beams emitted from point sources can be included, however, in product-specific standards, such as in IEC 60825-2 for optical fibre communication systems. This removal of Condition 2 is based on the conclusions that were already reflected in Interpretation Sheet 1 on IEC 60825-1 (ISH-1) [7] which in turn is based on work of the group of the author presented at ILSC 2009 [8]. While Class 1M and Class 2M in principle are not changed, they will in the future be restricted to characterize products where exposure with telescopes can be hazardous, and no longer apply to highly divergent beams.

Class 1C

A new class is introduced, Class 1C, where C stands for “contact” but in some interpretations also stands for “conditional” (see also ILSC 2009 paper by D Sliney and J Dennis [9]). Currently the class is limited to products intended for treatment of the skin or internal tissue in contact or close to the skin where the product is designed to be safe for the eye. However, the concept might well be extended to materials processing laser products which are used in contact with surfaces and feature sufficient engineering safety measures so that no eye protection is needed. It should be noted that a product is permitted to be classified as Class 1C only if and when a vertical standard exists that defines the requirements for the engineering means that make the product safe for the eye as well as that limits exposure level for the skin for the case of home-use devices (no need to limit the emitted power levels that are incident on the tissue for surgical devices). See also publication on Class 1C by John O’Hagan in these proceedings (Paper #C104 in the final plenary).

Light output Classified as Lamp

According to the CDV document, for special products it will be possible to assess the optical radiation output under the IEC 62471 series [10] and not under IEC 60825-1. This amendment was prompted by blue laser sources being used to produce white light by adding a phosphor (the same principle used to produce white LEDs based on blue LED chip) as well as laser radiation being used for cinema projectors. The emitted optical radiation of such systems is also either broadband (phosphor) or at least multi-wavelength, as well as either diffuse (phosphor) or extended sources (projectors). However, because the radiation is produced by a laser beam, the product falls under IEC 60825-1 (in the same way as a product, where *no* laser beam is emitted, such as a DVD player or burner, falls in the scope of IEC 60825-1 and needs to be classified according to IEC 60825-1). The problem was dealt with by IEC TC76 by permitting that the emitted light is treated under IEC 62471 when the product is designed to function as conventional light source and when the radiance of the product is below $(1\ \mathrm{MW \cdot m^{-2} \cdot sr^{-1}})/\alpha$, where α is the angular subtense of the apparent source specified in radian (α limited to values between 0.005 rad and 0.1 rad). If there is no “normal” laser radiation accessible, these products will be classified as Class 1, where the optical radiation that functions as light source is “neglected” for the classification based on IEC 60825-1; this optical

radiation will be assessed under the IEC 62471 series of standards. See also paper by C Stack #C104 in the final plenary. A specific safety standard for this kind of products is under development and, while the current CDV of IEC 60825-1 does not require it, it might be case that a requirement will be inserted that the above described approach (classification of the output beam as broadband radiation under IEC 62471) is only permitted when a vertical product specific standard specifies specific safety requirements.

Risk Analysis

Also the role of risk analysis was emphasized in the 3rd edition of IEC 60825-1, as discussed in more detail in Paper #601 of these proceedings [11]. While this is not really a change in the requirements, the amended text helps to strengthen the role of risk analysis not only in terms of probability of exposure but also in terms of actual risk for injury based on injury thresholds.

Alternative Labels

After a long development process and earlier attempts, symbol-labels are given as an alternative to worded labels to reduce the burden for manufacturer regarding multiple language labels for products (however, for the higher hazard classes, the labels still include some worded warnings). Some examples are given in Figure 1.

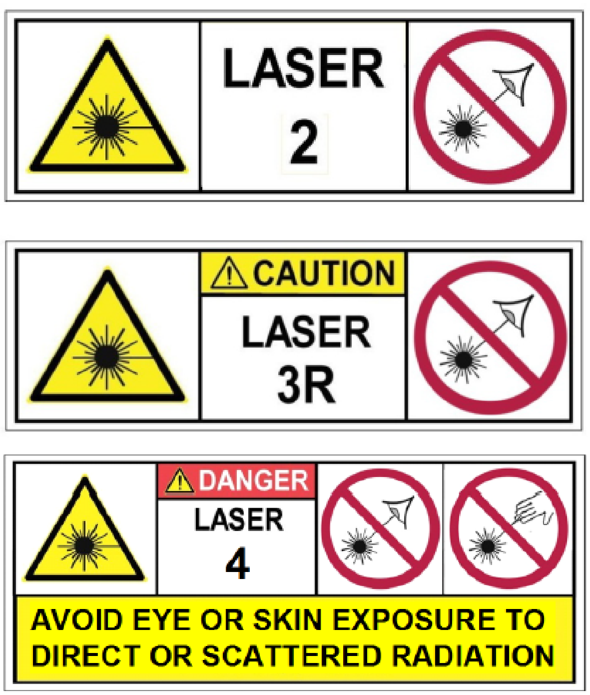

Figure 1. Examples of alternative labels according to IEC 60825-1 CDV

Engineering Specifications

There were some adjustments in the engineering specifications, such as that for hand-held battery powered Class 3B devices there is no need for a remote interlock connector. For Class 3R outside the wavelength range of 400 nm – 700 nm, instead of an emission indicator, a momentary switch that must be continually depressed to allow emission is permitted. Some requirements were improved in under-standability and clarified with notes.

Presentation of MPEs also as "Power through Aperture"

Following the example of ICNIRP (see also [12]), the MPEs for the eye in the wavelength range of 400 nm to 1400 nm were, besides the usual presentation as irradiance/radiant exposure (with exposure level averaged over 7 mm) presented also as "permitted power/energy through a 7 mm aperture" which is often easier to communicate and understand (for instance the MPE is 1 mW for 0.25 s in the visible).

Reorder of Clauses

Last but not least, the main Clauses were reordered to reflect the practical process: first, the class needs to be determined (now Clause 4, 5), and then, corresponding to the class, product safety features (such as key switches) – now Clause 6 – and warning labels (now Clause 7) are required. In earlier editions of IEC 60825-1, the engineering specifications and labels came first and then the test requirements for determination of the class were specified.

Changes of MPEs and AELs

The bio-effects and the injury threshold data base were reviewed in earlier presentations at ILSC as well as in a review paper [13] and will not be discussed here.

In the subsequent sections, the changes of the limits and the impact for products are discussed. Whenever the term "limits" is used, it means MPEs for retinal thermal injury as well as the AEL for Class 1, Class 2 and Class 3R as applicable (i.e. Class 3R being 5 x the AEL of Class 1 or Class 2 depending on wavelength range).

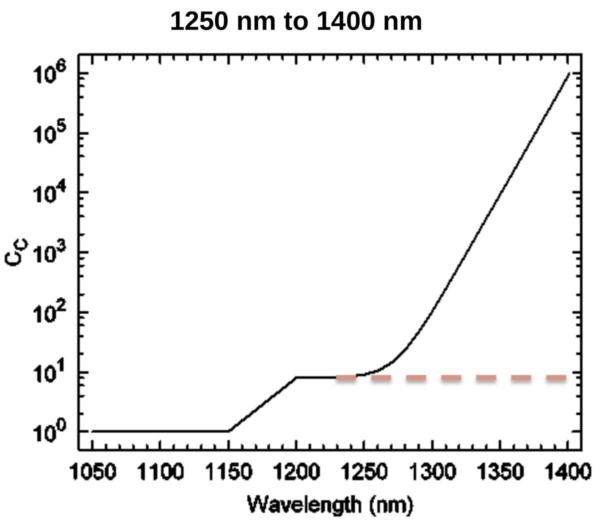

Figure 2. Current (dashed) and new factor C_C (C_7). Note that there is also a new dual limit to protect the anterior parts of the eye, not shown here.

The factor C_C (ANSI, ICNIRP) and C_7 (IEC) is significantly increased in the wavelength range of 1250 nm to 1400 nm. In the current edition, C_7 remains at a value of 8 for wavelengths between 1200 nm and 1400 nm as shown in Figure 2 by the dashed line.

The new C_7 features an exponential factor that is added to the level of 8 and that leads to significantly higher values starting at wavelengths of about 1250 nm.

$$8 + 10^{0{,}04(\lambda-1250)} \quad \text{for} \quad 1200 \text{ nm} \leq \lambda \leq 1400 \text{ nm}$$

For the example of the wavelength of 1310 nm, often used in the telecommunication industry, the new factor C_7 equals 259, which is a factor of 32 higher than the current factor C_C (C_7).

For a wavelength of 1400 nm, the factor equals 10^6, which is a factor of 125 000 higher than the current value. However, the exposure of the eye is not permitted to reach those high levels, as a dual exposure limit was introduced to protect the anterior parts of the eye. There are two different approaches to set this dual limit. The IEC 60825-1 CDV deviated here from the ICNIRP guidelines and adopted the ANSI dual limit to protect the cornea; the corresponding table is given in Figure 2. This dual limit is specified for the wavelength range of 1200 nm to 1400 nm and will be the limiting value for large values that are permitted for the retinal thermal exposure limit. It depends on pulse duration, wavelength and spot size which of the two is the more restrictive value. The dual limit was developed by the ANSI committee (the wavelength factor is referred to as K_λ there, it is C_8 in the IEC CDV) to be an extension of the "normal" corneal limit that applies for wavelengths above 1400 nm, with the difference between ICNIRP and IEC updated exposure limits, that the ANSI corneal limit and skin MPE for the wavelength range of 1400 nm to 1500 nm were raised by a factor of 3 for pulses up to 1 ms compared to the current levels; the equivalent limits were not changed on the ICNIRP and IEC level. Therefore, for the case of the IEC CDV document, there is a step function of 3 at 1400 nm for pulses up to 1 ms (and a smaller step function for longer pulses, and no step function at 10 s) between the new dual limit shown in Figure 3 and the "normal" corneal exposure limits starting at 1400 nm (and there is no step function in the ANSI set of limits at 1400 nm).

Table A.5 – MPE of the cornea to 1 200 nm – 1 400 nm laser radiation

Exposure time t s	MPE $J \cdot m^{-2}$
10^{-11} to 10^{-3}	$3\ C_8$
10^{-3} to 4	$3\ C_8 + 5\ 600\ t^{0{,}25} - 1\ 000$
4 to 10	$7\ 000 + 3\ C_8$
10 to 30 000	$3\ C_8 + 1\ 000\ t - 3\ 000$

Where $C_8 = 10^3 \times 10^{0{,}01(1\ 400-\lambda)}$
The radiant exposure is to be averaged over the limiting aperture (in mm)
1 for $t \leq 0{,}35$ s
$1{,}5\ t^{3/8}$ for $0{,}35\ s < t < 10$ s
3,5 for $t \geq 10$ s

Figure 3. Table A.5 of IEC 60825-1 CDV; new dual MPE for the eye to protect the cornea (necessary since the retinal thermal limit is increased dramatically)

It should be noted that this dual limit is only given in the (non-normative) MPE section of IEC 60825-1, and is not reflected in the classification in this form. For classification, according to the CDV for Class 1, 1M, and 3R the upper range of emission is limited to the AEL value of Class 3B for the wavelength range between 1300 nm and 1400 nm, i.e. for cw sources to 0.5 Watt. For small sources (C_6=1), the wavelength where the new "retinal thermal" AEL for Class 1 reaches 0.5 Watt is at 1310 nm, i.e. for wavelengths longer than 1310 nm and small sources, the Class 3B AEL is the limiting factor; for extended sources with higher retinal thermal AELs, this limitation will occur at a shorter wavelength.

For practical applications of the exposure limit for the eye it also has to be considered that in this wavelength range, the MPE for the eye can be higher than the MPE for skin; therefore, the higher MPE for the eye would only apply for cases where only the open eye is exposed. If the requirement is not to exceed the exposure limits (for the eye or the skin), then the skin MPE would be the limiting factor.

The ICNIRP approach was to limit the exposure of the eye (for cases where only the eye is exposed) in the

wavelength range of 780 nm to 1400 nm to twice the exposure limit of the skin. For the visible wavelength range, where for pulsed sources with large apparent sources also high retinal exposure limits are permitted, the iris needs to be protected and here the dual limit is given by ICNIRP as the skin exposure limit.

Reduction for Nano-second Pulses

For single pulses (for multiple pulses see subsequent sections) for pulse durations below the current T_i of 18 µs for wavelength up 1050 nm and T_i = 50 µs for wavelengths between 1050 nm and 1400 nm, the new limit will be lower, since the new T_i equals 5 µs and 13 µs, respectively. This is in effect a lowering of the limits for small sources and single pulses by a factor of 2.5 (see Figure 4).

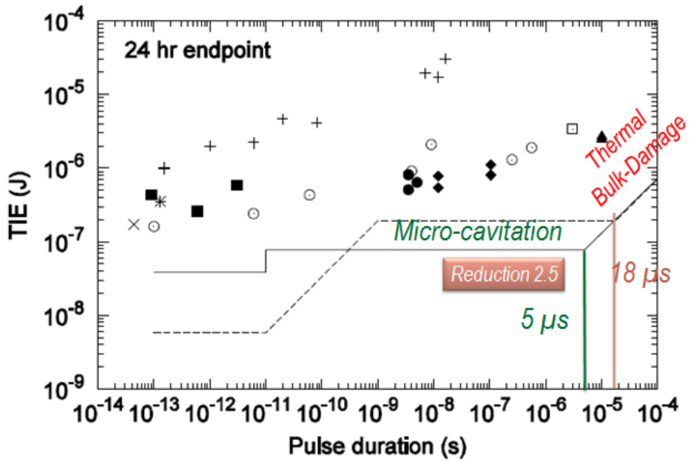

Figure 4. Threshold data plot courtesy of D Lund and BE Stuck, with current (dashed) and new (line) exposure limits.

The same reduction factor applies to the complete wavelength range of 400 nm to 1400 nm, but for wavelengths above about 1250 nm is counteracted by the increase of C_7. It also has to be emphasized that this reduction of the single pulse limit is in many cases compensated for by making the rules for multiple pulses less restrictive, and for extended sources by the introduction of a time dependent α_{max}.

Increase for Ultrashort Pulses

As is shown in Figure 4, the limits in the ultrashort pulse duration range were raised by extending the nanosecond limit (constant energy/radiant exposure) down to 10 ps. The cross-over point, when the new single pulse limits become higher than the current one is at 312 ps. At 10 ps there is a step-function of 2 and then again a constant energy/radiant exposure limit value for shorter pulses down to 10^{-13} seconds (100 fs). This new limit for pulse durations less than 10 ps is, for visible wavelengths, a factor of 6.5 above the current limit. Note that the factor C_4 (C_A in ICNIRP and ANSI; derived from the wavelength dependence of retinal absorption for wavelengths above 700 nm and reaches a value of 5 for 1050 nm to 1400 nm) is only applied to the limits longer than 10 ps; for shorter pulses, C_4 is not part of the limit and therefore, the step function of 2 only applies in the visible wavelength range. For 1400 nm, for instance, due to the lack of C_4 for shorter pulses, the step function is a factor of 10. Since the current limit contained the factor C_4 also for pulse durations less than 10 ps, the new limits for the case of 1400 nm are only a factor of 6.5/5 = 1.3 above the current limits.

Time Dependent α_{max}

For pulsed extended sources, the effective permitted emission level can increase by up to a factor of 20, depending on angular subtense of the apparent source and pulse duration. While the limit as such does not change, the value of α_{max} is limited to a pulse duration dependent value which can be as small as 5 mrad:

$$\alpha_{max} = \begin{cases} 5 \text{ mrad} & \text{for } t < 625\ \mu s \\ 200\, t^{0.5} \text{ mrad} & \text{for } 625\ \mu s \le t \le 0{,}25 \text{ s} \\ 100 \text{ mrad} & \text{for } t > 0{,}25 \text{ s} \end{cases}$$

For exposure durations/emission durations above 0.25 s, i.e. for cw emission, nothing changes since α_{max} remains at 100 mrad. For sources that are larger than α_{max}, $C_6 = \alpha_{max} / \alpha_{min}$ (i.e. a smaller value as before) but only the ***partial*** emission which is within α_{max} is to be compared to the emission limit, so the level that originates from the total apparent source can be correspondingly larger. For a homogeneous circular source profile with $\alpha > \alpha_{max}$, this effect of reduced accessible emission is equivalent to comparing the total energy with the limit (and not only the part within α_{max}), and increasing the limit with a factor of $C_6 = \alpha^2/(\alpha_{min}\, \alpha_{max})$. This is shown in Figure 5 as a relative increase as function of angular subtense of the apparent source. The lower line is the current dependence, and the lines that branch off to higher values come from the new pulse duration dependent α_{max}. The maximum difference between old and new limit sets is a factor of 20 which applies to pulse durations less than 625 µs where α_{max} = 5 mrad and for angular subtense values of 100 mrad or larger. It is noted that the treatment of the time dependent α_{max} by increasing C_6 with the square of α is only applicable to homogenous circular sources; for irregular sources, or non-circular sources, the analysis has to be done with a field of view restricted to α_{max}).

Obviously this change only affects pulsed sources and sources that are extended, larger than 5 mrad.

Examples for extended sources are diffuse sources (for instance used for hair removal), diffractive optical elements and VCSEL arrays with individual emitters spaced close enough (so that the analysis method for irregular extended sources does not apply to one emitter anyway).

For pulsed extended sources, the retinal limits are increased to such high levels that exposure at or below the exposure limits for the retina, the iris can be injured. Since such sources have to have a larger divergence (the angular subtense cannot be larger than the divergence, see for instance [5, 14]), this situation is only relevant if the emitter is close to the eye. ICNIRP has defined a dual limit for the eye as not to exceed the skin limit for visible wavelengths and twice the skin MPE for wavelengths in the infrared range. In the CDV for IEC 60825-1, there is no dual limit explicitly specified for that case (only for the wavelength range of 1200 nm to 1400 nm), but because the eye-lid is covered by skin, the skin MPEs are in practice an "automatically" implied dual limit (otherwise the person would not be allowed to blink). This might be amended for the published standard to explicitly set a dual limit for the case that only the eye is exposed. For classification, that issue (which for the classification is also about potential injury of the skin at contact) is accounted for in the CDV for IEC 60825-1 by requiring a warning label on the product when the AEL for Class 3B is exceeded where the accessible emission is determined with a 3.5 mm aperture in contact with the product. For diffuse sources, the permitted power for Class 1 or Class 2 is particularly high, mainly because of the classification distance of 100 mm and C_6 (also for cw sources). For the example of a Class 2 cw product, and a diffuse source of 1 mm diameter, the permitted emitted total power equals 5.4 Watt and for 5 mm diameter source 27 Watt (see paper #P107 in these abstracts). In the view of the author, it is questionable whether this approach is sufficient to produce an acceptable product, i.e. where the exposure at contact can induce quite severe skin burns but the product is Class 1 and there is only a warning label on it. For consumer products, this might not be acceptable.

Multiple Pulses - Small Sources

For small sources and extended sources up to 5 mrad angular subtense, for pulse durations longer than T_i, the pulse additivity factor C_5 (C_P in ANSI and ICNIRP) will be equal to 1 (according to ANSI CDV, also for pulse durations shorter than T_i which is referred to as t_{min} in the ANSI document). Setting C_5 = 1 leaves the single pulse limit and the average power limit as applicable for multiple pulse exposures/emissions. It depends on the pulse repetition frequency if the average power or the single pulse limit is the limiting factor. This critical repetition frequency can be calculated and for the example of the wavelength of 400 nm to 1050 nm equals 13 kHz for an exposure duration/time base of 0.25 s, and 5 kHz for an emission duration of 10 s, respectively. For pulse repetition rates less then these values, the single pulse limit is the limiting one.

The resulting increase in output levels, compared to the current multiple pulse rules is significant: for the case of 0.25 s exposure duration/time base, the permitted energy per pulse is up to a factor of 7.5 higher and for an emission duration of 10 s, up to a factor of 15.

For pulse durations less than T_i (5 µs up to 1050 nm wavelength, 13 µs for > 1050 nm), the rules are different between ICNIRP/IEC and ANSI CDV: in the ANSI draft, no multiple pulse reduction factor is needed in the nanosecond range, while according to ICNIRP and IEC, for the case that the assumed exposure duration or time base is longer than 0.25 s (i.e. Class 1, not applicable for Class 2) and the number of pulses N exceeds 600 within that time base, the factor

$$C_5 = (N/600)^{-0.25}$$

As shown in Figure 5, the factor 1/600 in C_5 means that for N=600, C_5 = 1 and then decreases with $N^{-0.25}$, as is known from the current factor. The equivalent presentation is to specify $C_5 = 5 \cdot N^{-0.25}$ for N > 600, as $600^{0.25} = 5$.

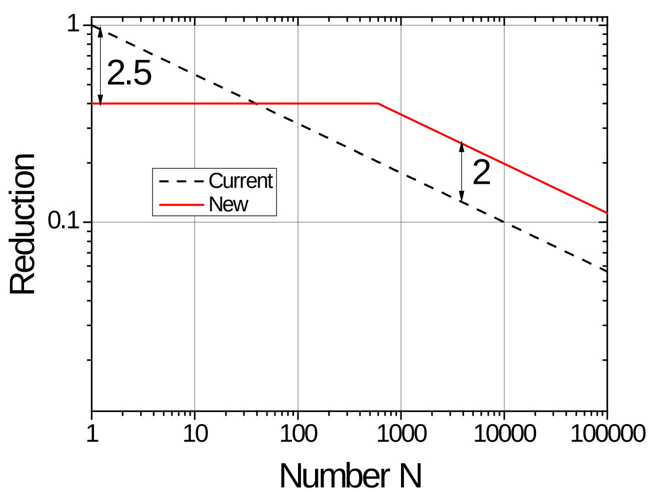

Figure 5. Relative change of the exposure limit for multiple pulses with pulse durations less than T_i (5 µs for 400 nm to 1050 nm; 13 µs for 1050 nm to 1400 nm)

Since the single pulse limit is reduced by a factor of 2.5 and the new limits will remain at that lower level

up to 600 pulses while the current limit starts to decrease with $N^{-0.25}$ right away, the new limits are more restrictive than the current ones only for pulse numbers up to N=39. For $N \geq 600$ the new limits are a factor of 2 *LESS* restrictive than the current ones.

In the ANSI committee, the majority of the experts considered it not necessary that a reduction factor is needed for pulses shorter than 5 µs (for arguments see [15]) However, there is no non-human primate threshold data available to support that approach, which is why it could not be supported by ICNIRP.

Multiple Pulses Extended Sources

For extended sources, the situation is different, as there a reduction is needed to account for the additivity of pulses: the factor C_5 is defined for pulse durations longer than T_i in IEC CDV and ANSI CDV as follows:

α > 5 mrad: $C_5 = N^{-0,25}$ with following max. reductions (max N):

$\alpha \leq \alpha_{max}$: max-C_5 = 0.4 (max-N = 40)
$\alpha > \alpha_{max}$: max-C_5 = 0.2 (max-N = 625)

α > 100 mrad: $C_5 = 1$

This means that while the "old" reduction factor applies for sources between 5 mrad and 100 mrad angular subtense, the reduction value is limited to not less than 0.4 for sources smaller than α_{max} and to not less than 0.2 for the case of sources larger than α_{max}.

Again, the average power and the single pulse rules also apply in parallel. It is not straight forward to specify for which conditions which rule is the limiting one. The analysis was performed and is accepted for publication in JLA [16], but it is rather complex and more of an theoretical value, for instance regarding the question of how to optimize a product design for a given class, and in practice, for existing products, it might be easier to just apply all three rules and see which one is the most restrictive one.

Summary

The changes in the upcoming new editions of the laser safety standards IEC 60825-1 and ANSI Z136.1 are summarized. The impact of the changes of the exposure limits for the eye is discussed. Some of the factors of permitted higher emission are significant and often lie in the range of 10-20. For single pulses in the nanosecond range it was necessary to reduce the limit by a factor of 2.5.

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Meet the Author

Karl Schulmeister, PhD, is a consultant on laser and broadband radiation safety at the Seibersdorf Laboratories, where also a specialized accredited test house is operated. Karl is a member of ICNIRP SCIV as well as of ANSI ASC Z136 TSC-1 (Bioeffects). He also serves as the secretary of IEC TC 76 WG1, the working group responsible for IEC 60825-1. The research in his group over the last six years concentrated on thermally induced injury that also provided the basis for amending the spot size dependence and multiple pulse rules of the retinal thermal limits.